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TECHNICAL NOTE NO. 1421
AUGUST 1961

AIR BLAST DATA FOR CORRELATION WITH MOVING AIRFOIL TESTS

W. E. Baker
W. J. Schuman, Jr.

Department of the Army Project No. 503-04-002
Ordnance Management Structure Code No. 5010.11.815

BALLISTIC RESEARCH LABORATORIES

ABERDEEN PROVING GROUND, MARYLAND

B A L L I S T I C   R E S E A R C H   L A B O R A T O R I E S

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A B E R D E E N   P R O V I N G   G R O U N D ,   M A R Y L A N D

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Aberdeen Proving Ground, Md
August 1961

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ABSTRACT

In this note, the author presents air blast data in a form which allows prediction of a number of "free-field" air blast parameters during the interaction of a blast wave with a moving target. The data are based on sources of compiled blast measurements and on theory of blast waves generated by explosives, and are presented graphically on large-scale plots.

NOMENCLATURE

W	effective free-air weight of Pentolite, lb.
R	distance from charge center, ft.
$Z = R/W^{1/3}$	scaled distance, ft/lb$^{1/3}$
t	arrival time, ms
Δt	positive duration of overpressure, ms.
λ	Brode's dimensionless distance
τ	Brode's dimensionless time
D_p^+	Brode's positive duration of overpressure
U	shock velocity, ft/sec.
u	particle velocity, ft/sec.
c_o	sound velocity, ft/sec.
P_s	peak side-on overpressure, psi.
P_o	ambient pressure, psi
$\bar{c}$	dimensionless sound velocity, $c_o/1086$ or $c_o/1139$
$\bar{p}$	dimensionless ambient pressure, $p_o/14.7$.
ρ_o	ambient density, lb/ft^3
T_o	ambient temperature, ^{o}K
a_o	charge radius, ft.

INTRODUCTION

In correlating data from experiments on the interaction of blast waves from conventional explosives with moving airfoils, one must know the characteristics of the incident blast wave with reasonable accuracy. Witmer[1*] has discussed in considerable detail the quantities which must be known. These include the following parameters:

(1) shock-front parameters

(a) overpressure
(b) particle velocity
(c) density
(d) arrival time

(2) time histories

(a) overpressure
(b) particle velocity
(c) density

The time histories should describe the variation with time of the blast parameters along the trajectory of the moving airfoil, rather than at fixed points in space.

In this note, we will discuss the manner in which air blast measurements, compiled data on air blast, and theories of air blast transmission can be used to give predictions of the required blast parameters, and will present large-scale curves of the blast parameters.

AIR BLAST MEASUREMENTS DURING AIRFOIL TESTS

During current experiments on blast loading of moving airfoils, some of the blast wave parameters have been measured directly with fixed, ground-mounted equipment. The blast source consists of blocks of TNT, stacked in roughly hemispherical form, on wooden tables a short distance[**] above a steel reflector plate. The data obtained include

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* Superscript numbers denote references at end of note.

** At scaled heights of < 0.3 ft/lb$^{1/3}$.

arrival time and the time histories of overpressure at several locations in the vicinity of the airfoil and, for charges > 2000 lb. in weight, time histories of overpressure at a number of additional locations about the explosive charge. From the measurements none of the desired shock-front or time histories desired can be determined directly, but an effective free-air weight of explosive can be estimated by comparing the peak overpressures and durations of overpressure (or positive impulses) with sources of compiled data on conventional explosives.

AIR BLAST PROPERTIES INFERRED FROM COMPILED DATA

We will in this note base predictions of air blast parameters which can be inferred from experiment on a recent compilation of Goodman[2] of free-air data on bare spherical Pentolite. As mentioned in the previous section, the effects of change of type of explosive and of ground reflection can be accounted for by comparing measured overpressures and durations at various distances with the smoothed curves in Goodman's report and estimating an equivalent weight of Pentolite detonated in free air. For planning of experiments, one can assume that 1.1 lb. TNT $\approx$ 1 lb. Pentolite, and that the weight of Pentolite in free air is equivalent to 1.8 times the weight on the ground.

Goodman presents compiled experimental data on peak overpressure and duration of overpressure, and also infers arrival time from the measured values. R. Shear and B. D. Day[3] have computed other shock-front properties as functions of overpressure using the Rankine-Hugoniot equations. Using Goodman's curve of overpressure versus scaled distance, one can then generate corresponding curves of peak particle velocity and peak shock velocity. All of these quantities are plotted in Figure 1 to a scale large enough to allow reading to three significant figures. The overpressures range from 0.6 psi to 100 psi, which should encompass values likely to be encountered in tests of airfoils.*

* For these curves, sound velocity is assumed to be that for 14.7 psi pressure and 300°K temperature, i.e., c_o = 1139 ft/sec.

From Figure 1, all of the desired shock-front parameters can be determined, as well as the duration of overpressure. But we must rely on predictions from theories of blast wave propagation for estimates of the time histories of density and particle velocity, since almost no reliable measurements of these quantities have been made.

AIR BLAST PROPERTIES INFERRED FROM THEORY

Of the available theoretical solutions of blast waves in air, the main work which is carried into the negative phase of the blast wave is that of H. L. Brode.[4,5,6] Although there are discrepancies in his work which we will mention later, we will use his solution. We will attempt to correlate his calculations for blast waves from TNT, given in references 5 and 6, with our compiled data for Pentolite, and then present large-scale plots of his results which will yield time histories of overpressure, density and particle velocity.

By trial and error, R. Shear of these Laboratories has fitted Goodman's smoothed curve[2] of measured overpressure for Pentolite to Brode's computed curve for the same blast parameter for TNT. This conversion was achieved by assuming that Brode's dimensionless distance λ could be converted to Goodman's scaled distance in charge radii, R/a_o, by multiplying by the constant 79.5, i.e.

$$R/a_o = 79.5\,\lambda \quad \text{(1)}$$

This conversion also yields

$$Z = R/W^{1/3} = 10.82\,\lambda \text{ ft/lb}^{1/3} \quad \text{(2)}$$

and

$$t/W^{1/3} = 9.85\,\tau \text{ ms/lb}^{1/3} \quad \text{(3)}^*$$

* Symbol t here denotes any blast parameter with dimensions of time, such as arrival time, duration of overpressure, etc.

Figure 2 shows graphically the agreement between Goodman's experimental curve of peak overpressure and Brode's theoretical one, using the above conversion. The author has also used this conversion to compare Goodman's data on arrival time and positive duration of overpressure with Brode's computations of these parameters, and presents these comparisons in Figures 3 and 4. We see from Figures 2 and 3 that peak overpressures and arrival times are in excellent agreement, and from Figure 4 that overpressure duration agrees reasonably well for small scaled distances, with Brode's computed values falling below the experimental ones at larger scaled distances.

Although the disagreement in duration is not significant because of the large scatter in experimental data, other bits of evidence indicate that Brode's theory predicts durations of both overpressure and particle velocity which are too small. Baker, et al[7], have shown that the predicted response of beams to blast loading whose duration is inferred from Brode's theory is somewhat less than measured response. John M. Dewey[8] has shown that durations of particle velocity measured during detonation of large explosive charges are about 1.5 times Brode's predictions over a considerable range of scaled distance. Brode's calculations also lack internal consistency often yielding values of the same parameter read from different curves which differ by more than 10%.

In spite of the apparent discrepancies noted above, we will use Brode's computations to predict the time histories of overpressure, particle velocity, and density. Use of the conversion factor given by equations 1 through 3 will assure reasonably good agreement with the shock-front parameters given by Figure 1. After conversion, Brode's space-time plots of the three parameters mentioned above, given in reference 6, are reproduced here as Figures 5, 6 and 7*.

* In Brode's calculations, ambient conditions are assumed to be p_o = 14.71 psi and T_o = 273 °K, giving sound velocity c_o = 1086 ft/sec. and density ρ_o = 0.0864 lb/ft^3.

The plots are terminated at times corresponding to arrival of the second shock. Time histories of another blast parameter, the dynamic pressure, were also desired[1], but have been omitted from this note because Brode did not include them in his computations for TNT.

APPLICATION OF BLAST DATA

The data presented in Figures 1, 5, 6 and 7 yield predictions of blast waves generated by explosives detonated under sea level ambient conditions. Variations of ambient conditions can easily be accounted for by applying Sach's scaling laws[9] to these data, in the manner indicated by Witmer[1]. This is done by replacing scaled distance $Z = R/W^{1/3}$ by the parameter $R(\bar{p}/W)^{1/3}$, and scaled time $t/W^{1/3}$ by the parameter $t\,\bar{c}(\bar{p}/W)^{1/3}$. The overpressure is then given by $Ps/\bar{p}$.

Let us briefly describe how to use the data given here. From blast measurements in the field, one first establishes an effective weight of Pentolite. This is done by comparing peak overpressures, arrival times, and durations of overpressure measured at known distances from the explosive with the data of Figure 1 (using Sachs' scaling parameters given above). From this effective weight, the shock front parameters at the location of the moving airfoil are then estimated from Figure 1. The trajectory of the sled, measured during the airfoil test, is plotted on Figures 5, 6 and 7. Time histories of overpressure, particle velocity and density can then be synthesized by plotting the intercepts of the trajectory with the lines of constant values of these parameters.

DISCUSSION

The data and methods of applying them which are described in this note should yield as accurate predictions of the time histories of the various blast parameters as one can expect from the present state of knowledge. Because the shock front parameters in Figure 1 are based on many experiments, or are inferred from experiment by the simple

FIGURE 1a

COMPILED FREE-AIR BLAST DATA ON BARE SPHERICAL PENTOLITE

LEGEND FOR FIGURE 1b:

P_s = peak side-on overpressure, psi

Δt = positive duration of overpressure, ms

t = shock arrival time, ms

u = peak particle velocity, ft/sec

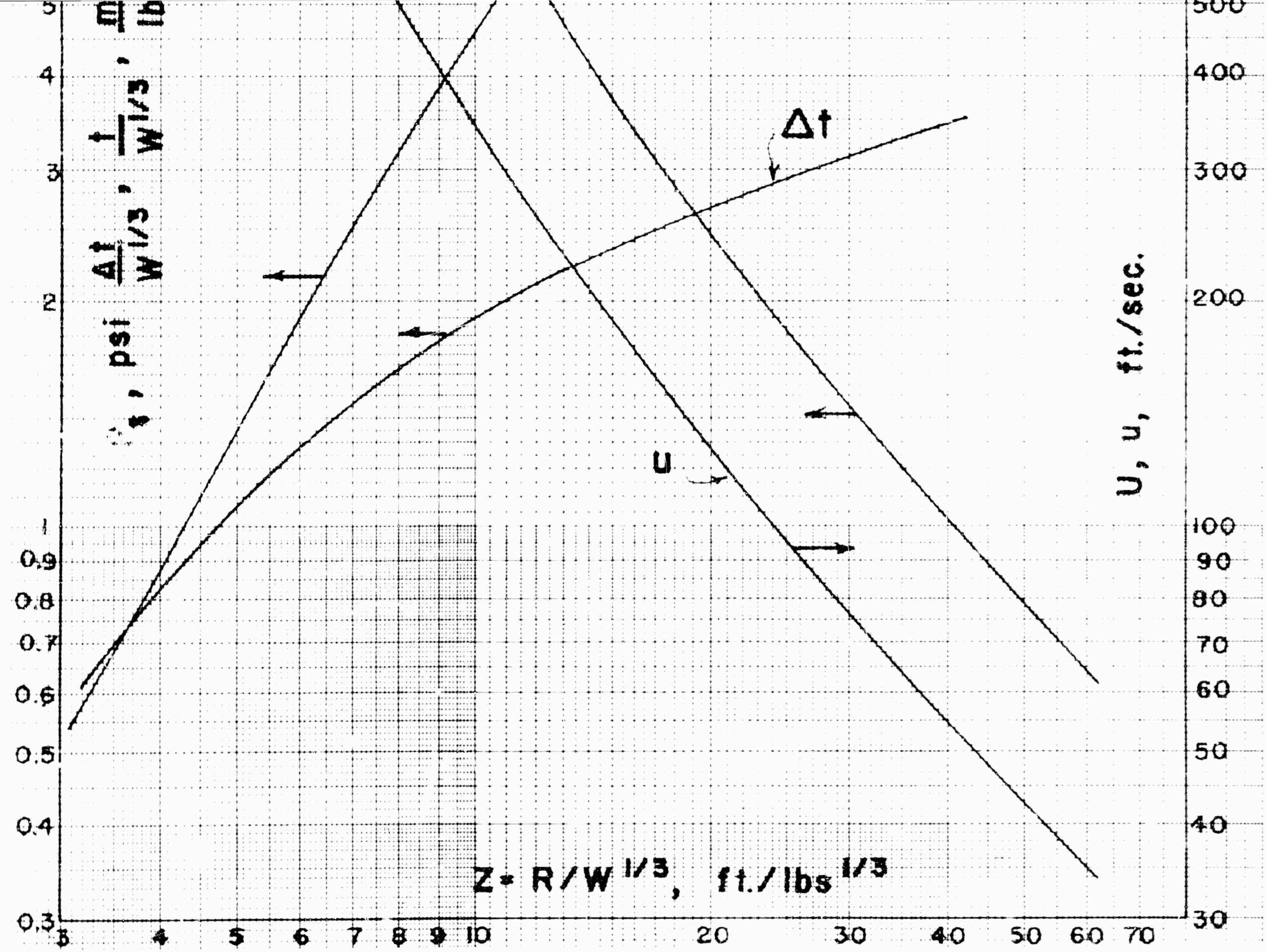
Z = scaled distance, ft/lb$^{1/3}$

R = distance, ft

W = weight of Pentolite, lb

U = shock velocity, ft/sec

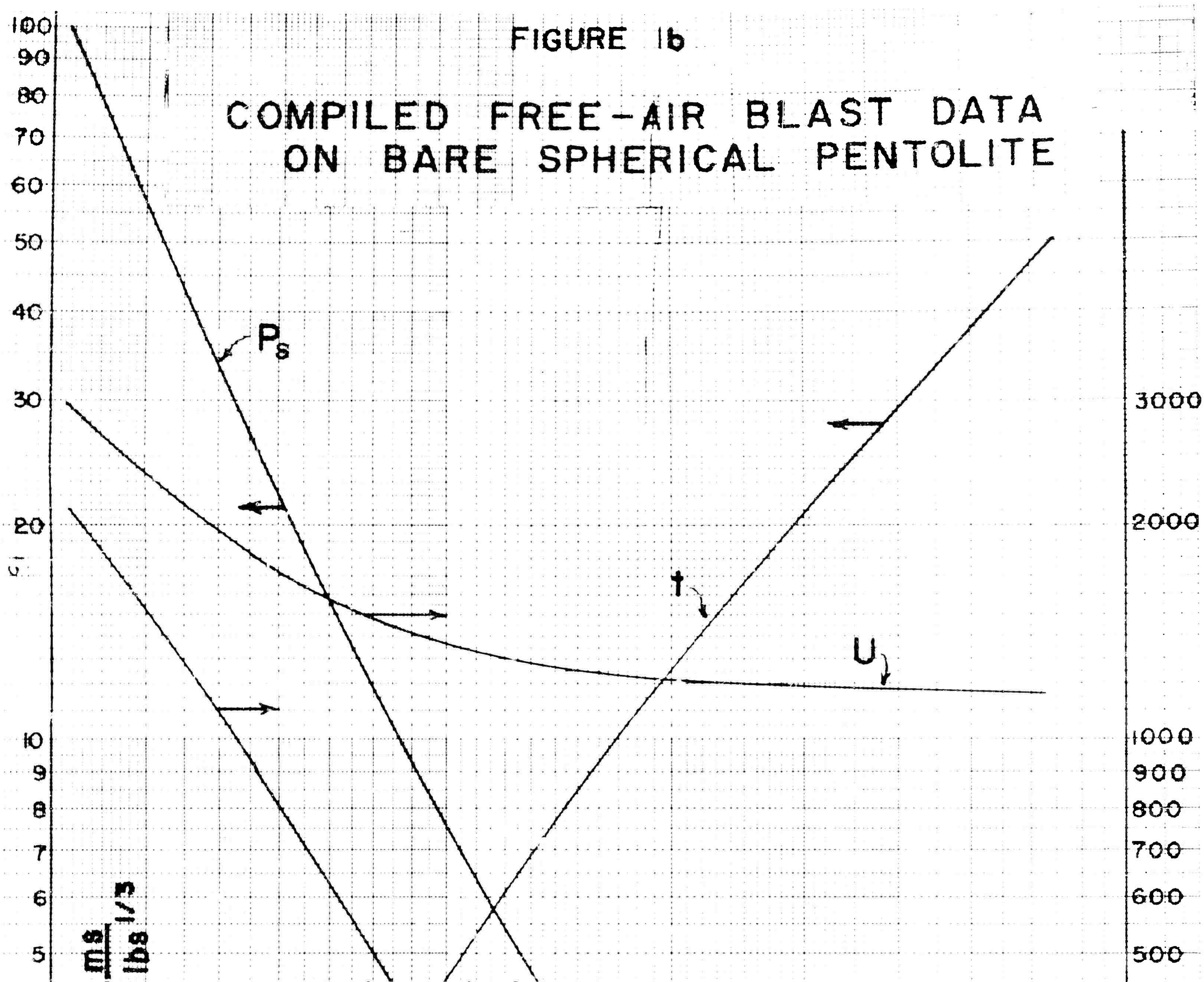
NOTE: Source of P_s, Δt, t is BRL 1092; u is computed from P_s using Rankine-Hugoniot Equations, as is U.

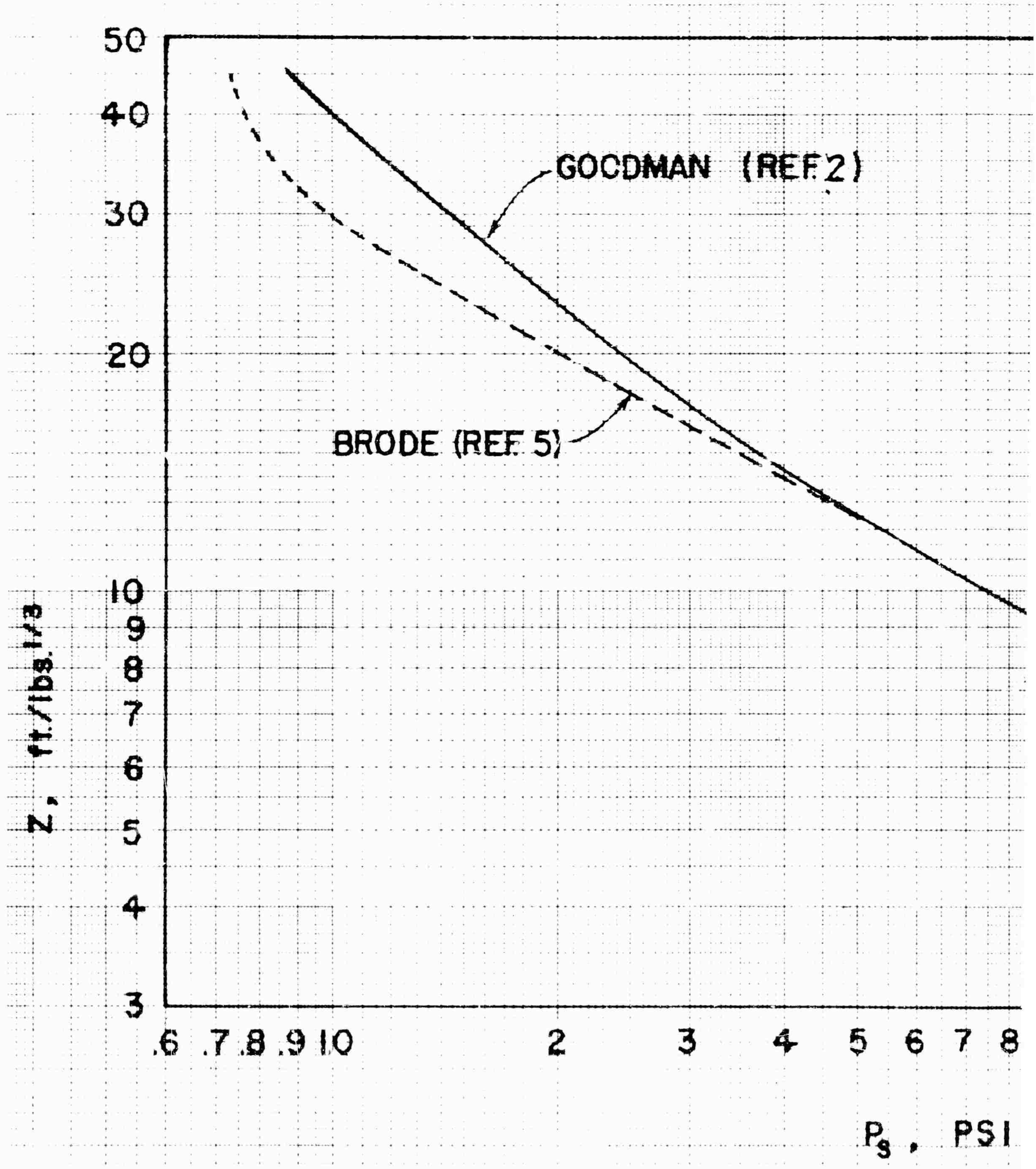


psi, Δt/W^1/3, t/W^1/3
Δt
u
U, u, ft./sec.
Z = R/W^1/3, ft./lbs^1/3
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2
3
4
5
30
40
50
60
70
80
90
100
200
300
400
500
3
4
5
6
7
8
9
10
20
30
40
50
60
70

FIGURE 1b

COMPILED FREE-AIR BLAST DATA ON BARE SPHERICAL PENTOLITE




GOODMAN (REF 2)
BRODE (REF 5)
50
40
30
20
10
9
8
7
6
5
4
3
Z, ft./lbs.1/3
.6 .7 .8 .9 1.0 2 3 4 5 6 7 8
P_s, PSI

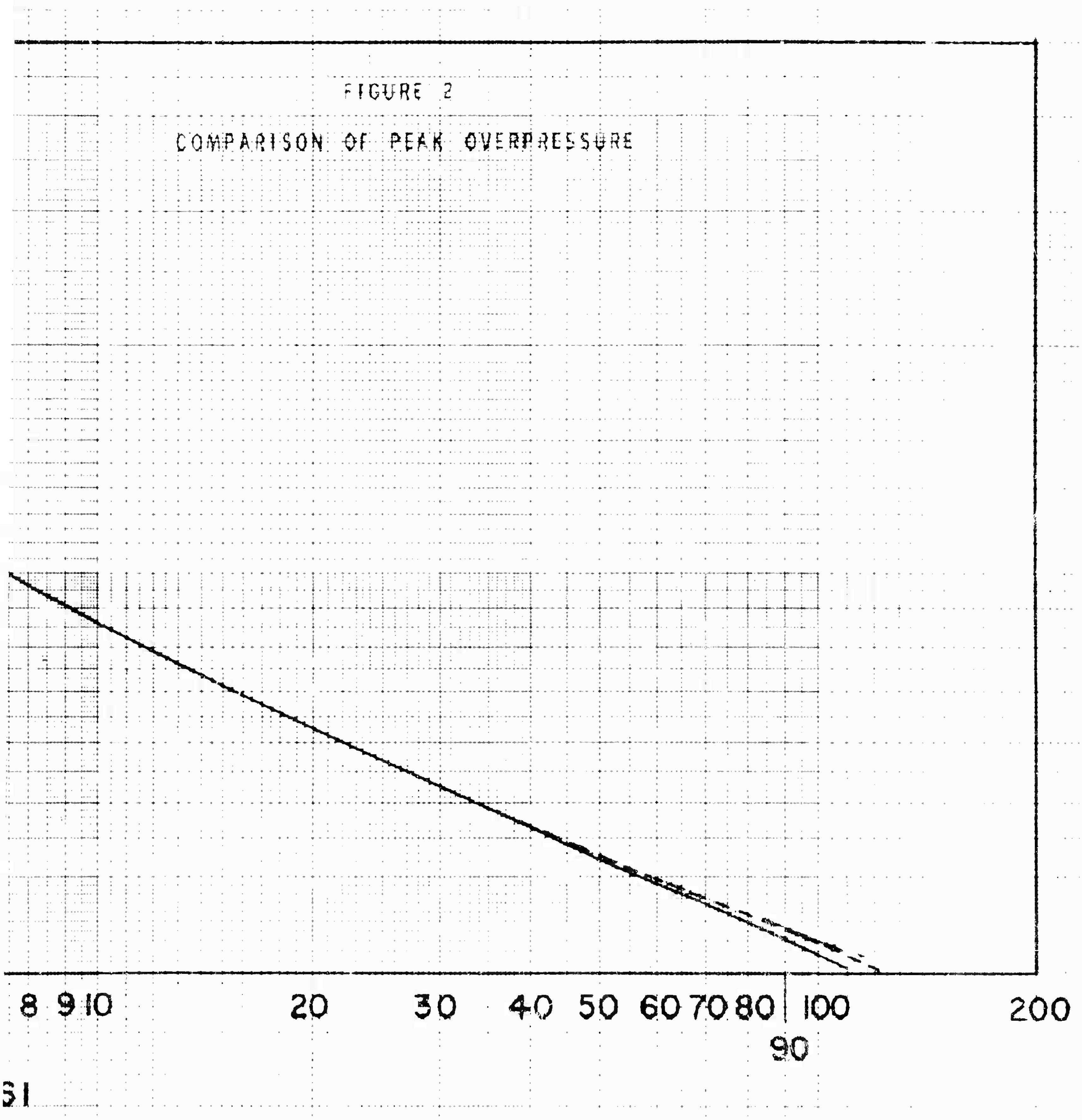
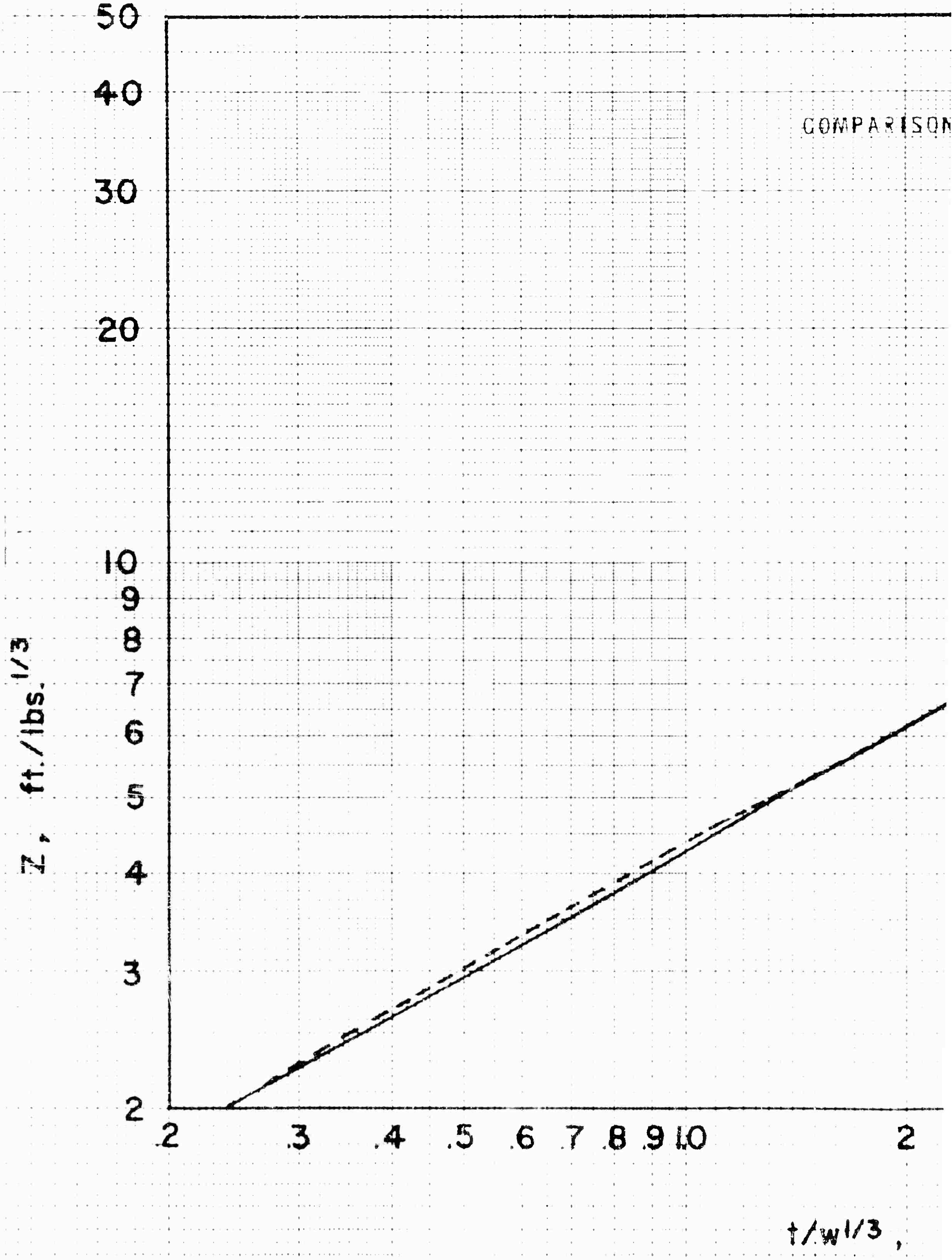


FIGURE 2
COMPARISON OF PEAK OVERPRESSURE
8 9 10
20
30
40
50
60 70 80
90
100
200


COMPARISON
50
40
30
20
10
9
8
7
6
5
4
3
2
Z, ft./lbs.^1/3
.2
.3
.4
.5
.6
.7
.8
.9
1.0
2
t/w^1/3 ,

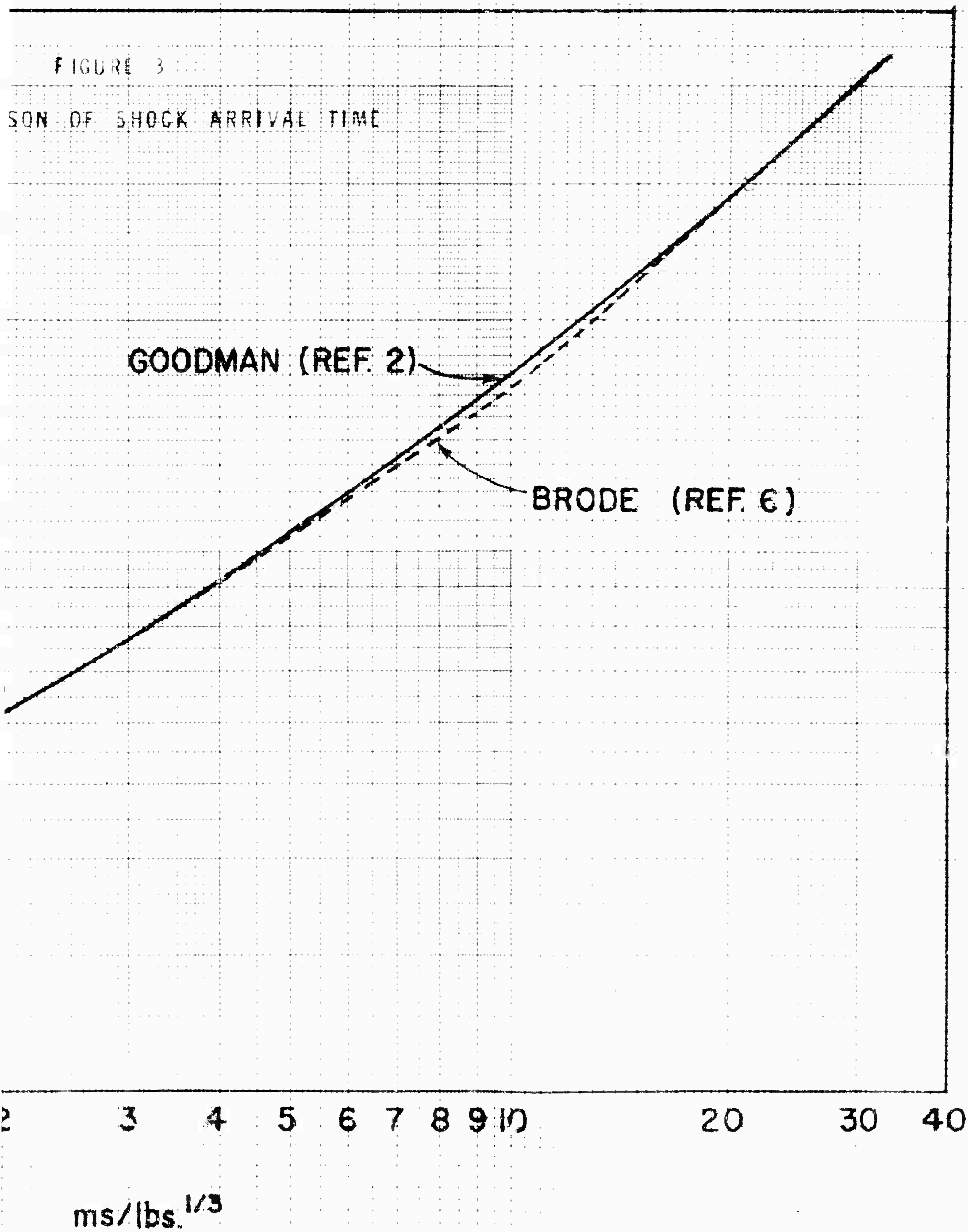
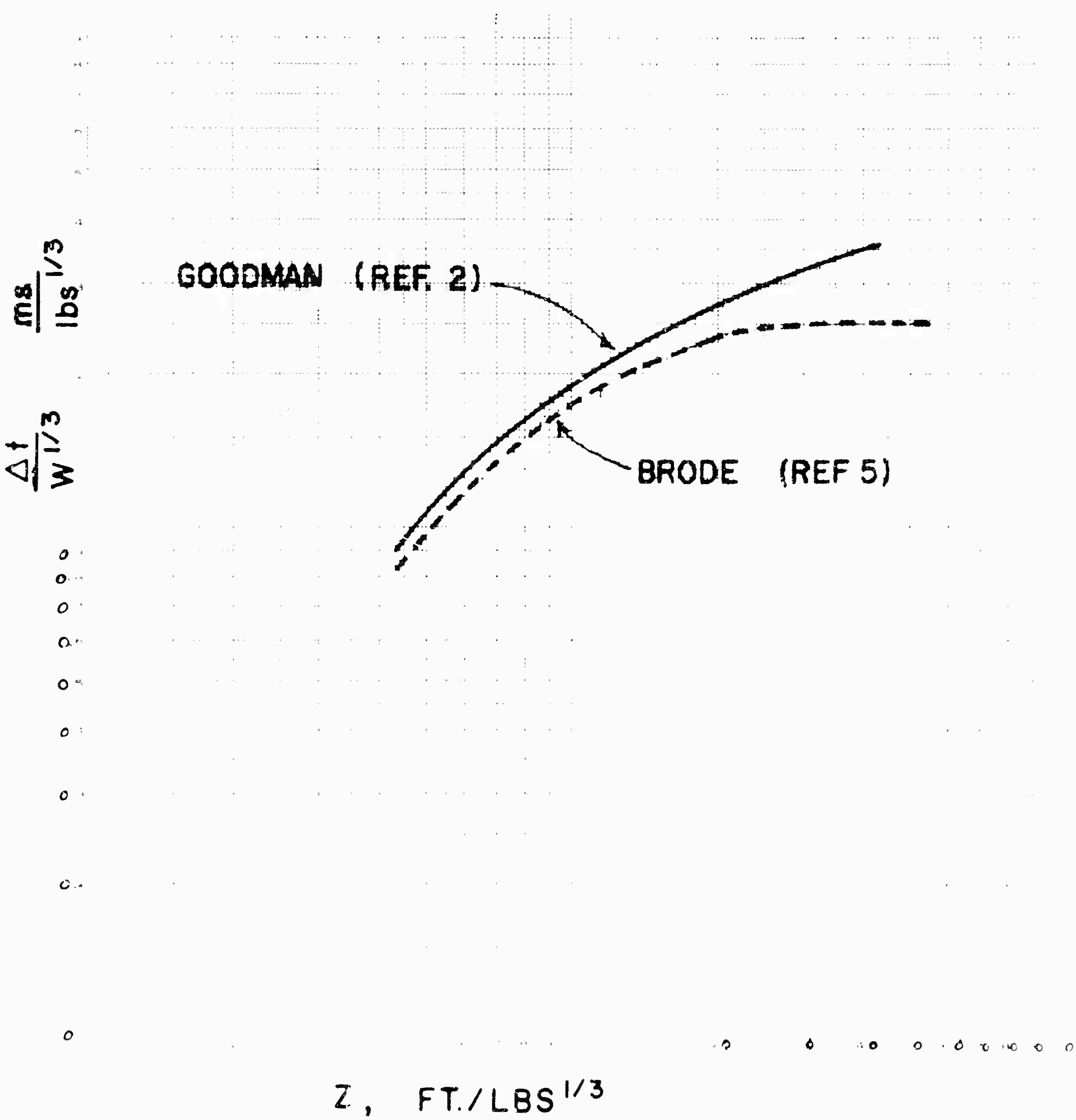


FIGURE 3
SON OF SHOCK ARRIVAL TIME
GOODMAN (REF. 2)
BRODE (REF. 6)
3 4 5 6 7 8 9 10 20 30 40
ms/lbs.$^{1/3}$

FIGURE 4

COMPARISON OF POSITIVE DURATION OF OVERPRESSURE



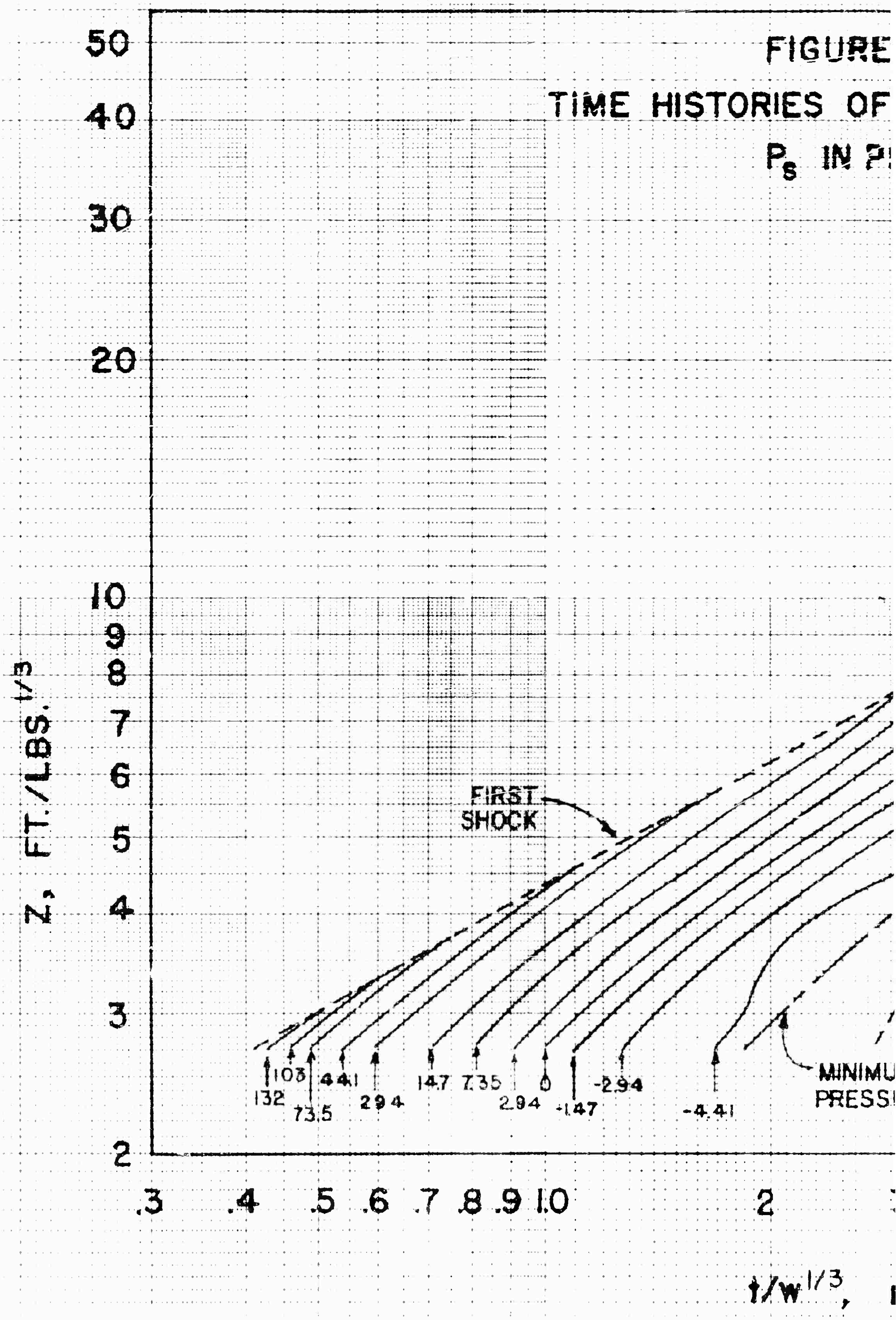
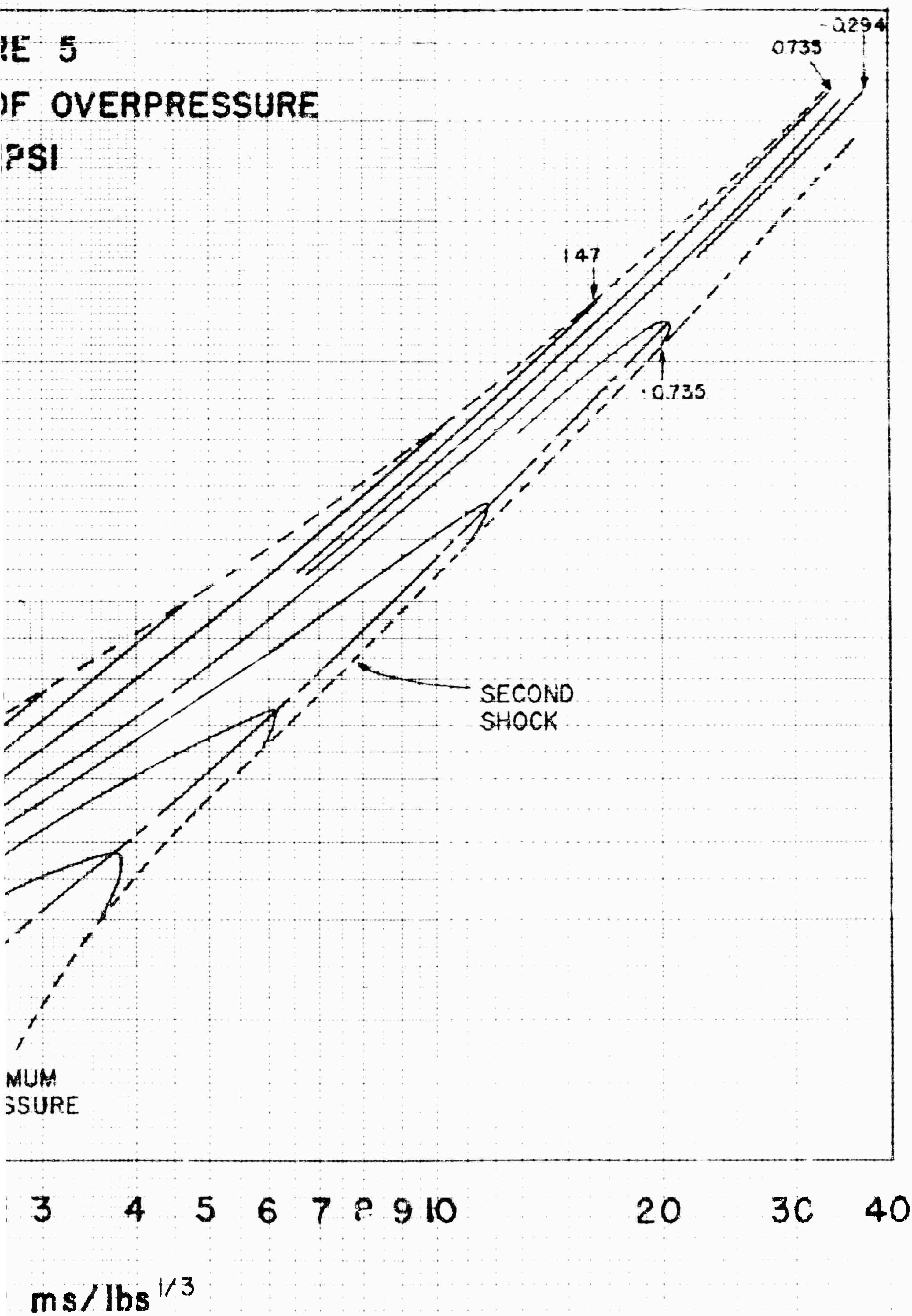


FIGURE
TIME HISTORIES OF
P_s IN P
50
40
30
20
10
9
8
7
6
5
4
3
2
Z, FT./LBS.$^{1/3}$
FIRST SHOCK
132
103
73.5
44.1
29.4
14.7
7.35
2.94
0
-1.47
-2.94
-4.41
MINIMU
PRESS
.3
.4
.5
.6
.7
.8
.9
1.0
2
t/w$^{1/3}$,



RE 5
OF OVERPRESSURE
PSI
0.294
0.735
1.47
0.735
SECOND
SHOCK
MUM
SSURE
3
4
5
6
7
8
9
10
20
30
40
ms/lbs$^{1/3}$

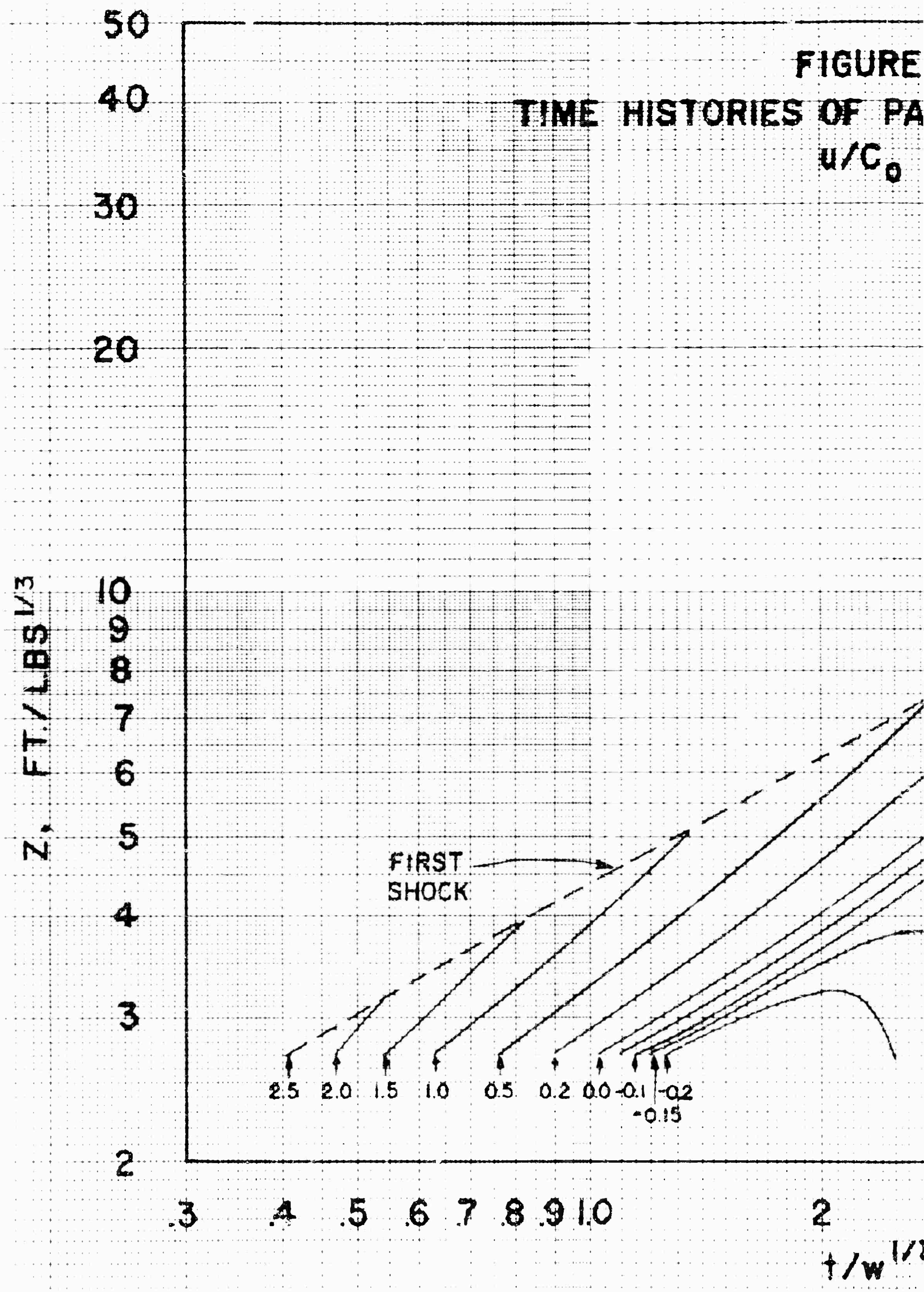
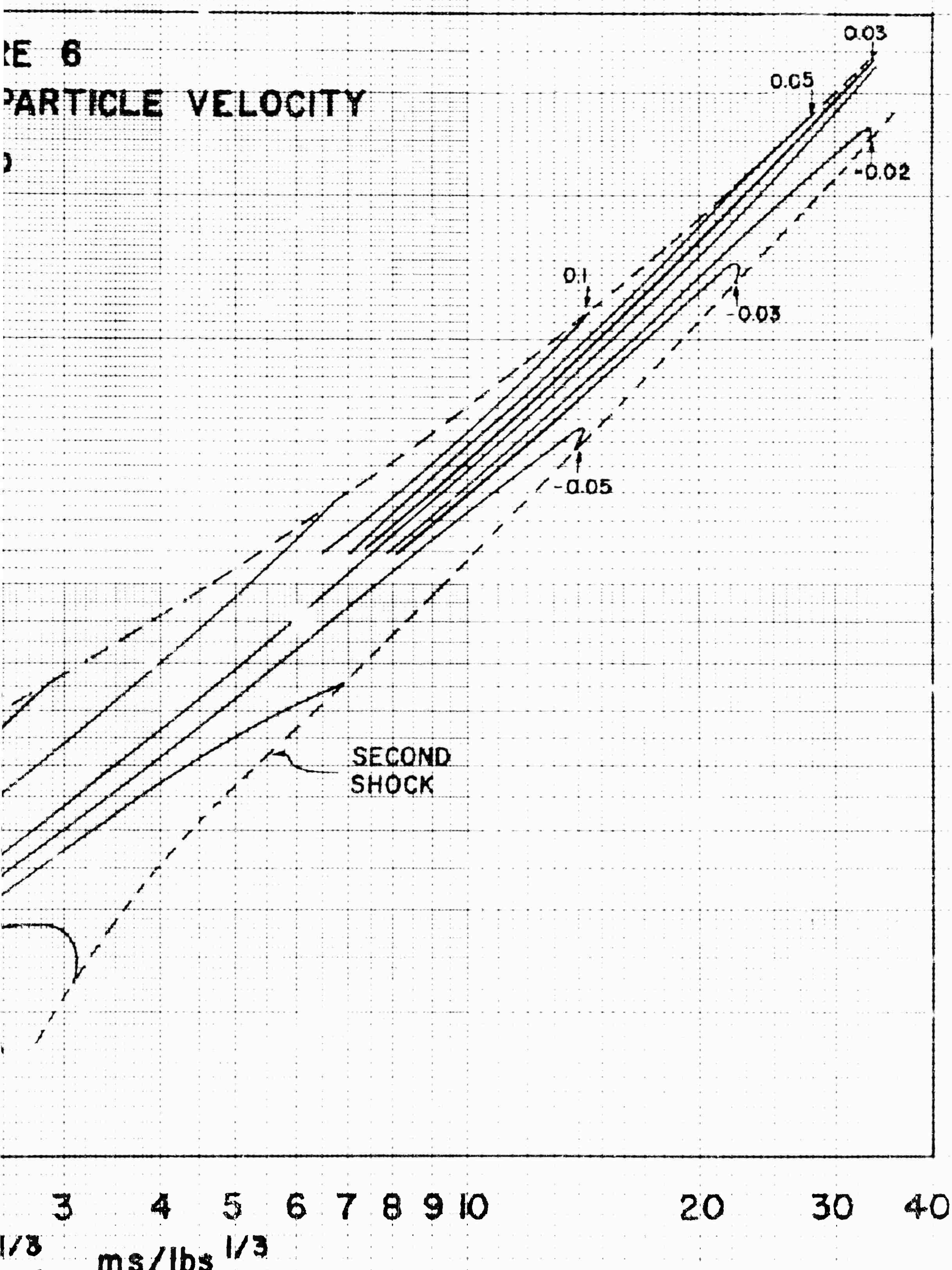
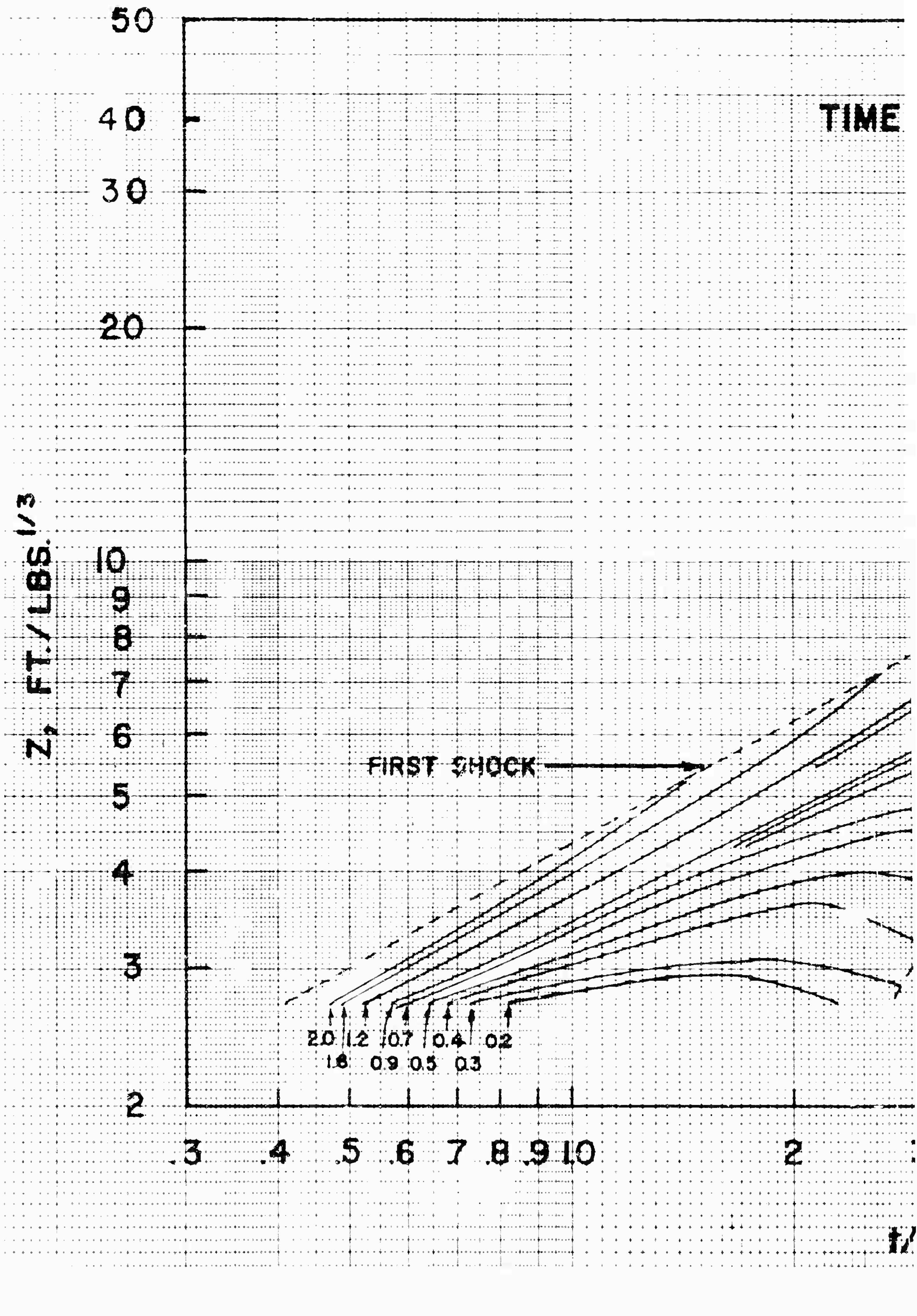


FIGURE
TIME HISTORIES OF PA
u/C0
FIRST SHOCK
2.5 2.0 1.5 1.0 0.5 0.2 0.0 -0.1 -0.2
-0.15
Z, FT./LBS 1/3
50 40 30 20 10 9 8 7 6 5 4 3 2
.3 .4 .5 .6 .7 .8 .9 1.0 2
t/w


RE 6
PARTICLE VELOCITY
0.03
0.05
-0.02
0.1
-0.03
-0.05
SECOND
SHOCK
3
4
5
6
7
8
9
10
20
30
40
ms/lbs 1/3



TIME
Z, FT./LBS.^1/3
50
40
30
20
10
9
8
7
6
5
4
3
2
FIRST SHOCK
2.0
1.8
1.2
0.9
0.7
0.5
0.4
0.3
0.2
.3
.4
.5
.6
.7
.8
.9
1.0
2

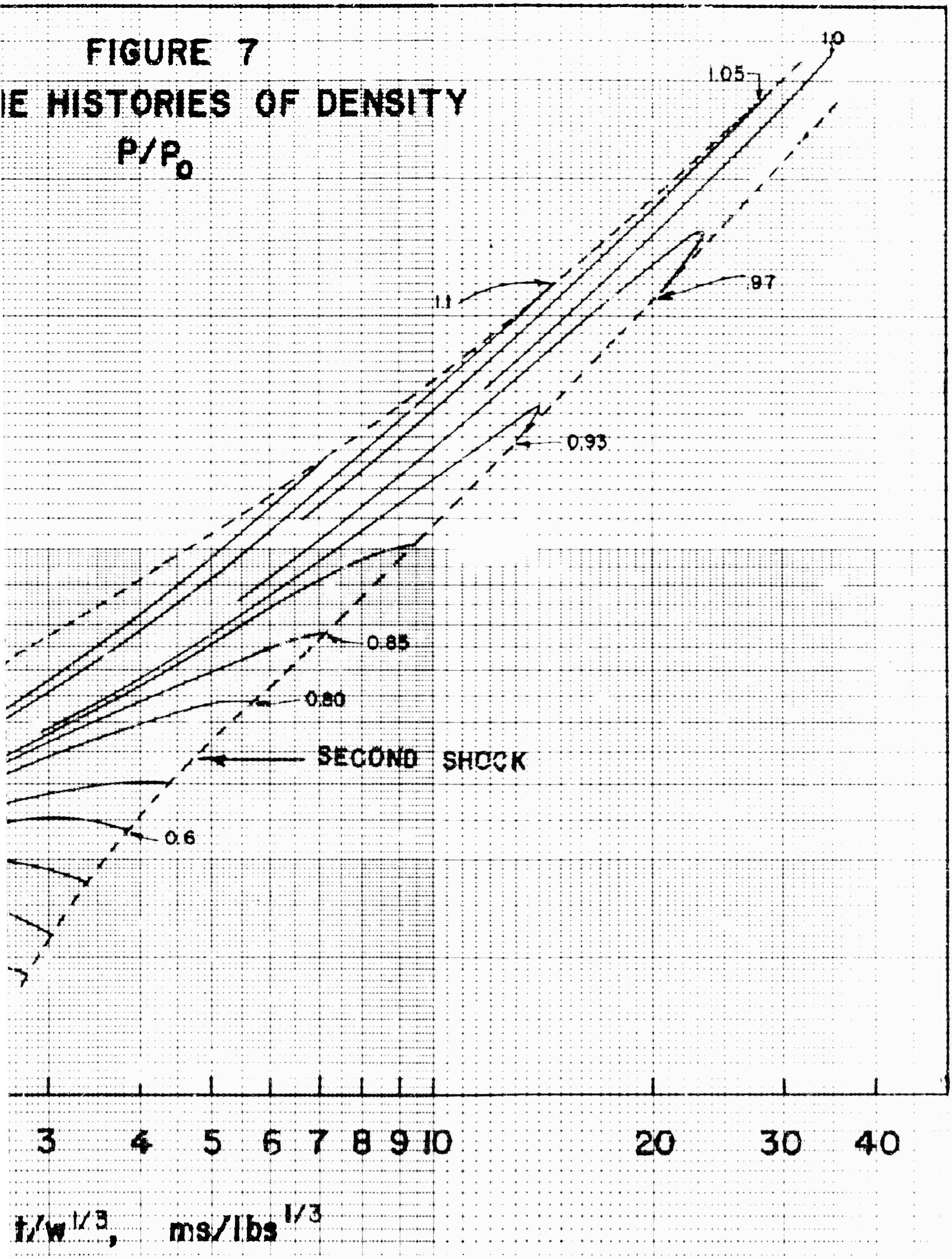


FIGURE 7
IE HISTORIES OF DENSITY
P/P0
1.0
1.05
1.1
.97
0.93
0.85
0.80
SECOND SHOCK
0.6
3
4
5
6
7
8
9
10
20
30
40
t/w1/3, ms/lbs1/3

Rankine-Hugoniot relationships, they should yield predictions accurate to within a few percent. The time histories were inferred from Brode's theory for lack of experimental data, and are very likely much less accurate, with the error increasing with increasing time after shock arrival. The durations of positive overpressure and of positive flow velocity may be as low as two-thirds of the true values for weak incident blasts.

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REFERENCES

1. Witmer, E. A. Data Required for the Aerodynamic Correlation of the JANAF Sled Test. Enclosure I to letter of 21 December 1960 to Wright Air Development Division, ATTN: Capt. J. S. Garner (WWRMDS), Wright-Patterson Air Force Base, Ohio.

2. Goodman, H. J. Compiled Free-Air Blast Data on Bare Spherical Pentolite. BRL Report No. 1092, February 1960.

3. Shear, R. and Day, B. D. Tables of Thermodynamic and Shock-Front Parameters for Air. BRL Memorandum Report No. 1206, May 1959.

4. Brode, H. L. Numerical Solutions of Spherical Blast Waves. Journal of Applied Physics, June 1955.

5. Brode, H. L. A Calculation of the Blast Wave from a Spherical Charge of TNT. Rand Corporation RM-1965, August 1957.

6. Brode, H. L. private communication with R. C. Makino of BRL, with six curves of properties of blast waves from TNT, 6 December 1960.

7. Baker, W. E., Ewing, W. O. Jr., Hanna, J. W. and Bunnewith, G. E. The Elastic and Plastic Response of Cantilevers to Air Blast Loading. BRL Report No. 1121, December 1960.

8. Dewey, John M. The Measurement of Air Velocity in a Blast Wave. Suffield Technical Paper No. 199, Suffield Experimental Station, Ralston, Alberta, Canada, 4 January 1961.

9. Sachs, R. G. The Dependence of Blast on Ambient Pressure and Temperature. BRL Report No. 466, May 1944.

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REFERENCES

1. Witmer, E. A. Data Required for the Aerodynamic Correlation of the JANAF Sled Test. Enclosure I to letter of 21 December 1960 to Wright Air Development Division, ATTN: Capt. J. S. Garner (WWRMDS), Wright-Patterson Air Force Base, Ohio.

2. Goodman, H. J. Compiled Free-Air Blast Data on Bare Spherical Pentolite. BRL Report No. 1092, February 1960.

3. Shear, R. and Day, B. D. Tables of Thermodynamic and Shock-Front Parameters for Air. BRL Memorandum Report No. 1206, May 1959.

4. Brode, H. L. Numerical Solutions of Spherical Blast Waves. Journal of Applied Physics, June 1955.

5. Brode, H. L. A Calculation of the Blast Wave from a Spherical Charge of TNT. Rand Corporation RM-1965, August 1957.

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